Impact of Porcupine Feeding Damage on Intensive Forest Management in the Prince Rupert Forest Region: Problem Analysis

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ABSTRACT

This report discusses the problem of feeding damage to trees by the porcupine (*Erethizon dorsatum* Erxleben) and intensive forest management in the Prince Rupert Forest Region. During winter months, porcupines feed on the vascular tissues of pole-size (10-30 cm dbh) trees. Damage is particularly significant in the second-growth western hemlock (*Tsuga heterophylla* Raf. (Sarg.)) -Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forests of the North Coast and Kalum Forest Districts. Porcupine populations have presumably been increasing in recent years in response to availability of preferred summer (early successional stages) and winter (15-to-35 year-old stands) habitats, as well as a moderate climate and low predator populations on the north coast of British Columbia.

Porcupine population fluctuations occur over very long periods. Dendrochronological analysis in northern Quebec indicates a significant expansion of porcupine populations in the last 25 years in response to climatic warming and development of forest stands suitable for winter foraging. Densities in spruce-balsam stands in New Brunswick averaged 2.3-3.1/100 ha, and across different forest types of Canada and the U.S. ranged from 0.4-82.3/100 ha. Home ranges in winter were smaller than those in summer and ranged from 0.1-12.1 ha.

Hunting, trapping, poison, and predator introduction are the major methods of population reduction. Hunting and introduction of the fisher appear to be the most promising techniques for reducing porcupine populations. Selection of less preferred tree species and leaving of sacrifice trees in management programs are two methods with potential for damage reduction.

Porcupines clearly prefer to feed on vigorous stems which are usually the dominant and co-dominant trees in natural and managed stands. This selective feeding on small non-merchantable stems leads to perpetual not satisfactorily restocked sites (NSR). In the relatively young (12-18 years) managed stands in the Kalum Valley, attack of western hemlock (the predominant species) has increased from 0.6% to 1.8% in the last two years. Similar stands in Alaska have cumulative damage of 25% of hemlock and 51% of spruce crop trees attacked by porcupines, and an annual rate of complete girdling (mortality) of 3.9%. These latter numbers may approximate the future damage situation for managed stands in the Kalum Valley. With limited quantitative data available, the impact of damage on allowable annual cut (AAC) has been viewed on an incremental or catastrophic basis. These two worst-case scenarios assume porcupine populations will continue increasing with consequent damage possibly reaching economically important levels. Both scenarios result in a significant lengthening of the rotation.

A first approximation of a forecast model to predict when and where outbreaks of porcupine damage will occur is outlined. Stands 25-35 years old (10-30 cm dbh) in the CWHf, i and j subzones on the north coast, which provide suitable winter habitat for porcupines, are particularly susceptible to attack. Management of stands may increase the intensity of attack. Specific recommendations to alleviate damage, and information and research needs, are outlined.

Key Words: intensive silviculture, porcupine, population, feeding damage, forecast model, western hemlock, Sitka spruce, barking, girdling.

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INTRODUCTION

The porcupine (*Erethizon dorsatum* Erxleben) is a well-known animal damage agent with a widespread distribution across the forests of Canada, southeast Alaska, and the northern and western United States. During winter months, this herbivore feeds on the vascular tissues (phloem and cambium) and foliage of pole-size to mature coniferous and hardwood trees. Barking injuries by the porcupine leaves broad (0.3 cm), prominent horizontal and diagonal incisor marks on the exposed sapwood (Lawrence *et al.* 1961). These barking and girdling injuries may have a considerable impact on intensive forest management.

Porcupine damage is common in many different forest types. In particular, a high incidence of porcupine damage has been observed in recent years in the second-growth western hemlock- Sitka spruce forests of the north coast (Prince Rupert Forest Region) of British Columbia. Sullivan *et al.* (1986) reported on the incidence of damage and its potential impact on growth and yield in the forest stands of Khutzeymateen Inlet. Eglitis and Hennon (1987) reported on the increasing rate of attack of crop trees by porcupines in precommercially-thinned stands in the central portion of the Alaska panhandle. Thus, the porcupine and its damage have considerable relevance to current and future silvicultural operations within the framework of intensive forest management in the Prince Rupert Forest Region. To this end, a problem analysis was initiated to discuss the problem, examine various alternatives of dealing with the problem, and develop criteria for selecting a course of action.

This analysis covered the following objectives in relation to intensive forest management:

1. synopsis of the general population biology of the porcupine.
2. assessment of the effectiveness and practicality of control strategies for porcupine populations and damage.
3. assessment of the impact of feeding damage on not satisfactorily restocked land (NSR), stand tending, and allowable annual cut (AAC).
4. development of a conceptual forecast model to predict when and where outbreaks of porcupine damage will occur.
5. development of a plan of action with an assessment of alternatives to control porcupine damage in the Kalum and North Coast Forest Districts.
6. information and research needs.

METHODS

Information on the population biology of the porcupine, as it relates to forest management, was synthesized from available literature. There have been a considerable number of studies conducted on porcupine populations and damage in various forest types across Canada and the United States. This information was used to assess which factors were relevant to the damage problem in the North Coast and Kalum Forest Districts. In particular, the role of forest management practices in generating suitable habitat for porcupines was emphasized in this assessment.

Assessment of the effectiveness and practicality of population and damage control strategies was synthesized from available literature and discussion with other workers in this field. Wherever possible, the efficacy of each strategy was based on scientific evidence so that the assessment would recommend realistic management tools for potential use. To this end, an objective critique of current control strategies has been included.

Assessment of the impact of damage on NSR, stand tending practices, and AAC used limited quantitative data from the North Coast and Kalum Forest Districts and from Alaska. This information was used to estimate the long-term impact on AAC and the short-term effects on NSR and stand-tending

objectives. The AAC analysis was related to potential long-term population fluctuations of the porcupine as reported in the literature. The impact of damage on tree growth and yield was assessed with respect to other studies on the porcupine and related small mammals. This overall analysis was designed to predict future trends for porcupine-damaged stands in the Forest Region.

A first approximation of a forecast model incorporated known information on porcupine populations, damage, and forest management scenarios in the Forest Region. Thus, it was based on general relationships and trends from work done to date. The consequent plan of action was based on this management model. It outlines survey methods for monitoring porcupine damage and populations, identifies susceptible forest types and suitability of control measures, and research requirements.

POPULATION BIOLOGY

Habitat Preference

Although porcupines exhibit intraspecific differences in feeding patterns within their extensive range in North America, there are similarities in foraging behaviour and diet preferences. Damage is more common in second growth than in mature or old growth stands (Golley 1956; Van Deusen and Myers 1962). Early successional habitats have greater amounts of herbaceous undergrowth during summer months which attract porcupines. Outbreaks of damage often appear in stands associated with recent logging or wildfire disturbance (Curtis 1941; Lawrence 1957; Yocom 1971). This situation has occurred in the hemlock-spruce forests of the north coast of British Columbia and the Alaska panhandle (Sullivan *et al.* 1986; Eglitis and Hennon 1986).

The tree species used may depend on availability (Speer and Dilworth 1978). However, porcupines feed on a wide range of species with hemlock (*Tsuga* Carr spp.), Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), and ponderosa pine (*Pinus ponderosa* Dougl.) predominating. There is a strong preference for trees less than 30 years old which corresponds well with the size of trees in pole-size stands. Such stands provide food, cover, and insulation during winter months. The size (dbh) of trees fed on by porcupines ranges from 3 cm to almost 90 cm (Table 1). The bulk of feeding occurs in pole-size trees from 7.6 cm to 38.1 cm dbh. Where information was available, vigorous trees such as co-dominants and dominants were more frequently attacked than those with less vigour (Rudolf 1949; Curtis and Wilson 1953; Van Deusen and Myers 1962; Krefting *et al.* 1962; Sullivan *et al.* 1986). Further evidence for this preference, based on radial growth analysis, has been reported by Spencer (1964), Storm and Halvorson (1967), and Harder (1979) for various species of conifers in the interior of North America.

As discussed by Harder (1979), vigorous trees with large open crowns produce a large annual increment of phloem (Bannan 1955; Grillos and Smith 1959), and provide more foliage and a greater volume of inner bark than trees growing in denser stands. Since porcupines usually feed on inner bark that is accessible from positions that can be maintained without undue exertion, open-crowned trees, which tend to provide more large branches, allow porcupines greater access to food. According to Kramer and Kozlowski (1960), the phloem and foliage of conifers contain the greatest concentrations of fats and carbohydrates of the aerial tissues. Thus, the tendency of porcupines to feed on these structures in the tree crown where growth is most rapid, presumably results in consumption of the most nutritious food available. This pattern was certainly evident in Khutzeymateen Inlet where the greatest intensity of feeding occurred in the mid and upper sections of hemlock stems (Sullivan *et al.* 1986). Porcupines may identify vigorous trees by their obvious physical features (Harder 1979). This has particular relevance to silvicultural strategies such as juvenile spacing and thinning which may predispose crop trees to porcupine attack because of their vigorous growth and accessibility.

Porcupine preference for crop trees in thinned stands has been reported by Van Deusen and Myers (1962) and Dodge and Canutt (1969) in the Pacific Northwest of the U.S., by Eglitis and Hennon (1987) in Alaska, and as reported from damage surveys in the Kalum Valley. Harder (1980) concluded that porcupines preferred *open* leeward stands in southwest Alberta.

TABLE 1. Range of tree sizes (dbh) preferred by porcupines in their feeding attacks

Source	Tree dbh (cm)	Stand
Sullivan *et al.* (1986)	27.5-32.4	hemlock/spruce
Clark (1958)	≤ 17.8	ponderosa pine
Harder (1979)	16.9-26.0	Douglas-fir
Roze (1984)	>3.0	beech/maple
Curtis & Wilson (1953)	20.3-25.4	ponderosa pine & Douglas-fir
Van Deusen & Myers (1962)	17.8-20.0	ponderosa pine
Krefting *et al.* (1962)	22.9-38.1	second-growth hardwoods
Rudolf (1949)	> 7.6	pine
Marshall *et al.* (1962)	> 17.8	conifer-hardwood forest
Taylor (1935)	10.2-25.4	ponderosa pine
Rudolf (1949)	17.8	Scotch pine
Rearden (1950)	7.6-15.2	Scotch & red pine
Daniel & Barnes (1958)	12.7-15.2	lodgepole pine
Spencer *et al.* (1948)	> 10.2	pinyon pine & ponderosa pine
Dodge & Canutt (1969)	30-52 75-90	unmanaged forests

Population Fluctuations

Although porcupine damage has been continually reported, the population biology of this animal is not well known. Porcupine population fluctuations occur over very long periods and may be indirectly tallied by dendrochronological analysis of feeding scars. A population in southwest Colorado underwent 4 fluctuations over a 120-year period, each spaced at about 10-20 years apart and each 12-20 years in duration (Spencer 1964). The last irruption was the most recent and the largest, lasting from the 1920's to the 1950's. The pattern was not like a logarithmic increase with a subsequent crash, as is observed in many small mammal populations (e.g. voles of the genus *Microtus*). There was a pyramidal pattern of population growth and decline. No explanation of this temporal variation was proposed.

These findings are supported by recent work using the same dendrochronological technique on white spruce in the Hudson Bay region of northern Quebec (Payette 1987). Again, the porcupine has made a significant expansion in the last 25 years, although they have occupied the area for the last 100 years in very low numbers. This expansion was attributed to the increase in spruce forests as a result of a warming in the climate during the last 100 years which provided more cover and winter forage for porcupines. The time lag between the forest expansion and the porcupine population increase may be due to the time required for new tree stands to achieve a certain age and dbh, and therefore, able to provide optimal foraging during winter. Thus, a time lag of several decades may be associated with

forest-niche building conducive to porcupines. It is also important to note that the fisher (*Martes pennanti* Erxleben) was reported as rare or absent from this study area and may have contributed to the geographical displacement of the porcupine. The fisher is a large weasel in the family Mustelidae, and is a principal predator of the porcupine. A similar expansion of porcupines in subalpine sites in Alberta may have resulted from predator control and lower hunting pressure (Gill and Cordes 1972).

Thus, the distribution of porcupines may be affected by climatic change in vegetation over long periods, and porcupine populations have the ability to expand into such regions provided conditions are favourable. Clearly, forestry practices such as logging provide an abundance of early successional stages (summer habitat) and second-growth pole-sized stands (winter habitat) within a forest mosaic in the North Coast and Kalum Forest Districts. Stand tending practices may provide even more attractive winter habitat with vigorous crop trees responding to thinning and fertilization treatments. Combined with a general climatic warming and lack of predators, it is perhaps not surprising that porcupine populations have increased to pest levels in this area. A similar increase in abundance of porcupines has occurred in the coastal forests of Washington, Oregon, and California in the last 20 years (Evans 1987). This climatic warming is expected to continue, perhaps indefinitely, and may have dramatic effects on forests and vegetation, in general (see review by Harrington 1987).

The number of porcupines in a given area tends to fluctuate greatly, depending on the season and food availability. Porcupines are solitary animals and occur at low numbers except for temporary concentrations due to a local food supply. There was a wide range of population densities recorded for the porcupine in various study areas of Canada and the United States (Table 2). Much of this variation may have depended on techniques of population estimation and forest habitat. Densities in mixed hardwood-hemlock forests of the north-central U.S. ranged from 0.4 to 82.3 porcupines (average of 19.9) per 100 ha. The other forest type somewhat similar to north coastal British Columbia, spruce-balsam fir in New Brunswick, had 2.3-3.1 porcupines recorded/100 ha. No reliable estimates of population density are available for the north coast or Alaska stands.

Home Range

Winter home range varied from 0.1 to 12.1 ha (Table 3). The somewhat anomalous result of Dodge and Barnes (1975) in this table may be explained by firmly crusted snow offering little barrier to movement, and their study site contained an abundance of den sites which made congregation in special denning areas unnecessary. In addition, the Dodge and Barnes (1975) study area of Douglas-fir-western hemlock forest contained an interspersed variety of seral stages that offered suitable forage for porcupines. This latter situation may be similar to that in the hemlock-spruce forest of the north coast of British Columbia. In general, the size of home range is affected by a number of factors such as ambient temperature, snowfall, available vegetation, and cover. However, despite this variability, winter home ranges were smaller than early summer and/or spring home ranges, which varied from 2.4 to 83.5 ha (Table 3).

Most of the winter feeding occurs within a short distance from dens and may in part contribute to the *hotspot* damage pattern often reported. It should be noted that porcupines do not necessarily need permanent dens but may inhabit temporary dens in periods of heavy rainfall or strong winds. In northern climates, however, dens provide necessary shelter during winter months. Den fidelity is high, although it is not uncommon for individuals to make 8-10 km moves when shifting home ranges due to disturbance or other factors (Roze 1987).

Seasonal Migrations

Porcupines will make seasonal migrations from open areas, which have herbaceous summer vegetation, into heavily wooded areas in autumn for a number of reasons. Firstly, dens are needed for breeding in autumn as this usually solitary animal becomes gregarious. Secondly, with the loss of herbaceous vegetation, porcupines must switch to feeding on the inner bark of woody plants (Harder 1979). In addition, conifers in winter offer more shelter than hardwoods (Speer and Dilworth 1978). In

spring, porcupines leave their shelters to feed in *open* areas during summer. The distances moved in these migrations range from 0.83 km (Krefting *et al.* 1962) to 10 km (Dodge 1982).

TABLE 2. Range of population densities estimated for porcupines in various study areas of Canada and the United States

Location and source	Density per 100 ha	Area surveyed & forest type
New York (Roze 1984)	10.7	216 ha beech-sugar maple
Michigan (Earle & Kramm 1982)	a) 0.4 b) 3.5	each site min. of 160 ha hardwood-hemlock
Oregon (Smith 1977)	12.6	259 ha mixed Douglas-fir & ponderosa pine
Michigan (Golley 1956)	>0.77	mixed hardwood-pine-swamp
Maine (Curtis 1944)	9.3	mixed hardwood-hemlock
Lake States (Krefting *et al.* 1962)	25.5-82.3	1020 ha hardwood-hemlock
Southwest U.S. (Taylor 1935)	1.2-5.8	ponderosa pine
Michigan (Powell and Brander 1977)	2.8	hardwood-hemlock
New Brunswick (Reeks 1942)	2.3-3.1	Spruce-balsam fir
Nevada (Randall 1971)	15.9	mixed pine-fir
Michigan (Brander 1973)	12.4, 16.6, 9.2	mixed hardwood-hemlock
Wisconsin (Stoeckeler 1950)	37.2	mixed hardwood-hemlock
Northern California (Hoffer 1967)	3.9	pine-juniper forest

Denning Habits

Porcupines will den in any convenient or ready-made cavity. Crevices and outcropping bedrock are common shelters in rugged terrain (Roze 1984). In conifer stands, down or windthrown trees, hollow logs, and scattered slash are often used (Hooven 1971). There is some suggestion that moist sites are preferred although this is not associated with having better accessibility to drinking water (Speer and Dilworth 1978). There is also evidence that a leeward community is preferred over a windward area (Harder 1979). In northern and coastal climates, most of the winter feeding will occur near the den, often on the same trees from year to year (Dodge 1982). Studies on the winter feeding pattern of the porcupine have shown that the percentage of gnawed stems decreased with increasing distance from dens (Curtis 1941). In shared dens, the immediate area could suffer significant damage, especially when year to year den fidelity is high (see Roze 1987).

CONTROL STRATEGIES

A wide variety of control methods have been tried to suppress porcupine damage. The most commonly-used technique involves poison (toxicants). This approach and a number of other methods will be reviewed for efficacy and applicability to forest protection. There are two major groups of control methods; those which reduce the population, and those which reduce the damage. In evaluating efficacy, not only the reduction of damage must be reviewed, but also the practicality of using a given method on a large scale in a forest stand.

TABLE 3. Home-range estimates (ha) for porcupines in various study areas of Canada and the United States

Location and source	Summer &/or spring	Winter
Northwestern Minnesota (Tenneson and Oring 1985)	-	0.2
Southeastern Idaho (Craig and Keller 1986)	23.1	0.1
Central New Brunswick (Speer and Dilworth 1978)	-	0.3
Pacific Northwest (Evans 1987)	-	12.1
New England (Faulkner and Dodge 1962)	2.4	-
New York (Roze 1987)	64.9	7.4
Minnesota (Marshall *et al.* 1962)	13-15	-
Western Washington (Dodge and Barnes 1975)	83.5	83.5
Northeastern Oregon (Smith 1979)	63.9	-

Population Reduction

Most of the control methods used, to date, belong to this category. The potential rate of population increase is very low for the porcupine which has just one offspring per year. Thus, techniques of population reduction are likely to be effective in reducing porcupine abundance for meaningful lengths of time. It should be noted, however, that there is no quantitative information relating population reduction to damage reduction (Evans and Matthews 1972; Evans 1987). The population reduction measures discussed here will be removal techniques based on hunting, trapping, poison, and predator introduction. In areas of noticeable porcupine damage, bounties are often established. Hunting is relatively *easy* to do as porcupines are slow moving animals, they are often found up in a tree, and they do not have to be tracked for long periods of time. In the instances where this was done, however, no significant differences in porcupine numbers were observed (Faulkner and Dodge 1962; Dodge 1982). No controls (checks) were used in these trials.

Trapping has also been recommended as a control measure since it usually ensures a high kill success (Evans 1987). However, no data were available regarding population densities prior to and after trapping. Traps are also non-specific and require constant attention.

Poisons such as strychnine and sodium arsenite baits have been reported as effective with a high kill success in certain regions (Neitro 1969; Hooven 1971). Again, percentage reduction in damage was not measured and no controls were mentioned. Attempts in the northeastern states with strychnine salt combinations have not proven to be successful, possibly due to a higher consumption by porcupines of tannin, an antidote for strychnine (Dodge 1962). Moreover, another disadvantage of poison bait stations is the adverse side effects. Anthony *et al.* (1986) reported six non-target species and over twice the number of animals killed due to secondary poisoning compared with the number of porcupines killed. Sodium arsenite is extremely toxic to man and requires careful handling. In addition, it must be placed in specific locations to minimize secondary poisoning, hence making it a time-consuming process. At present, there is no poison registered for use on porcupines in Canada.

Of all the predators of the porcupine, only the fisher has been considered as a biological control agent. Firstly, other porcupine predators, such as wolverines, cougars, bobcats, and coyotes do not prefer porcupines and often themselves exist at low densities. Secondly, the porcupine, despite its outer coat of quills, is still a relatively *easy* prey for the fisher owing partially to its slow gait.

Although there have been reports of fisher introduction leading to a consequent observed decline in porcupine numbers (Cook and Hamilton 1957; Powell and Brander 1977), only one study in this survey has discussed a field trial with a control. Earle and Kramm (1982) reported significantly less road-killed porcupines in a fisher-introduced area (0.4/km^2) than in a control area (3.5/km^2). This method offers more promising control potential than hunting, trapping, or use of poison as it is not based on the numbers killed as a measure of success but rather on observed porcupine densities after the treatment. Whether or not the decline in numbers correlates with a reduction in damage requires field monitoring of susceptible stands. It should be noted, however, that fishers prefer old growth forests over early successional habitats. Pole-size stands may be intermediate in terms of habitat use by fisher, and hence provide some potential for reducing porcupine abundance and damage.

Results of the Khutzeymateen fisher introduction, to date, are inconclusive (Figure 1). A total of 8 fisher have been introduced since February 1985. There was no radio contact with any of the fisher (implanted transmitters) as of December 1987. Thus, they have been killed, dispersed from the area, or were in underground dens during the fly-over to establish contact. Another method to determine if fisher are still in the area is required (e.g. snow tracks, information from trappers). The number of fisher required to establish a resident population is unknown. Earle and Kramm (1982) reported a density estimate of 3.6 fisher observations per 100 km^2 for a resident population that became established after reintroduction. Therefore, one or two fisher within the 13 km^2 area of stands in Khutzeymateen Inlet would presumably constitute a resident population and eventually reduce porcupine density. In terms of alternative food sources, both red backed voles (*Clethrionomys gapperi* Vigors) in mature stands and long-tailed voles (*Microtus longicaudus* Merriam) in early- to mid-successional stands after logging should provide adequate prey (Banfield 1974; Van Horne 1982).

In summary, controlled field experiments, such as the Khutzeymateen Inlet fisher introduction, are needed to assess the efficacy of these various control methods. The fisher introduction — and perhaps other predator enhancement — appears to be the most promising technique in terms of population reduction on a long-term basis. Once the initial effort of obtaining, transporting, and releasing fishers has been completed, the technique requires little attention. However, fur trapping efforts within the *introduction* area must be regulated to allow the fisher to establish and maintain a resident population.

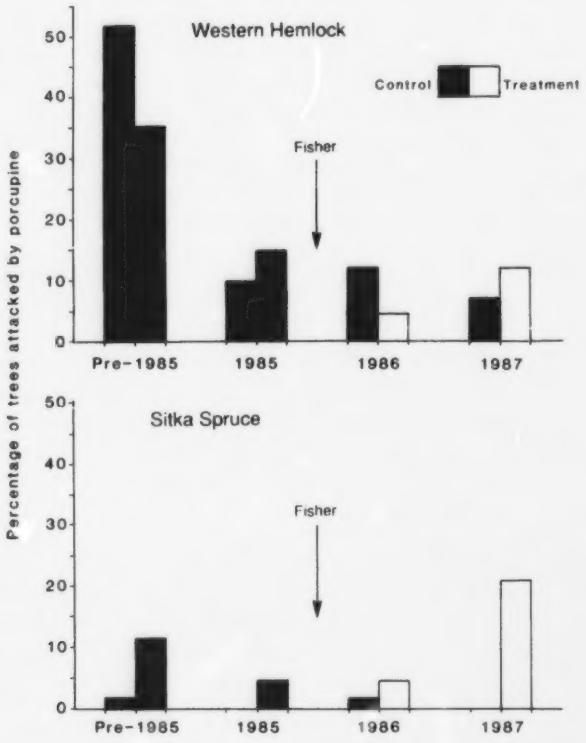

FIGURE 1. Percentage of western hemlock and Sitka spruce trees attacked by porcupine in stands on control and treatment sides of Khutzeymateen Inlet, fisher introduction experiment.

Damage Reduction

On a large scale, mechanical barriers such as fences and individual tree guards become too expensive both in material costs as well as labour (Dodge 1982). On the other hand, repellents, if applicable from the air or in a perimeter spray might be feasible. However, there are no repellents recommended for porcupines. Some paints and chemicals are unattractive to porcupines, but their use is limited to signs or posts and not applicable to trees. Furthermore, in some instances, porcupines have overcome their *dislike* of a chemical once they become accustomed to it (Dodge 1962; Milodragovich and Nettleton 1973).

In terms of forest management practices: thinning, leaving sacrifice trees, high grading, and pruning to make climbing difficult, have been suggested as ways to mitigate porcupine damage. A disadvantage of thinning is that although the damage may be temporarily reduced, the stand of pole-sized timber remains attractive to porcupines. As discussed earlier, there has been some evidence that thinning makes a stand more attractive to porcupines (Van Deusen and Myers 1962; Dodge 1982; Eglitis and Hennon 1986, 1987).

There is some correlation between percentage availability of a given tree species and percentage feeding (Speer and Dilworth 1978). However, if a preferred species becomes less abundant, the percentage feeding will also drop and porcupines may switch to a less-preferred species (Curtis 1944). Therefore, thinning that favours a less preferred species may not prevent porcupines from feeding on

those crop trees if they are numerically dominant. The sanitation spacing experiment (1987) at Mouse Creek, Khutzeymateen Inlet, is also incorporating tree species selection, sacrifice trees, and metal tree guards as damage control techniques. The 12-ha stand has alternating 8 m wide control and spaced (250 stems/ha) strips. The spacing favoured western red-cedar, amabilis fir, western hemlock, and Sitka spruce in that order. Within the treatment strips, spruce and hemlock have metal sleeves (87.5 cm high) whereas redcedar and fir do not. Crop trees in some strips were left unprotected. Thus, this experiment should provide information on: 1. porcupine preference for control or spaced trees, 2. tree species selection (i.e. will redcedar and fir be attacked since they were favoured in the spacing treatment?) 3. function of trees in control strips as sacrifice food with consequent reduction in porcupine attack of spaced trees, and 4. efficacy of metal sleeves to keep porcupines from climbing trees. Although not economically or logistically feasible over large areas, if the metal sleeves are effective (and expand accordingly with tree growth), then they could be implemented on a limited basis in small-area, high-value stands. This experiment is slated to continue for 5 to 10 years with annual damage assessments.

High grading, or decreasing the number of choice trees near used dens, should be researched more thoroughly as it has some potential for success. This method makes use of two aspects of porcupine biology. Firstly, winter ranges of porcupines are usually confined to a small area near their dens. Secondly, porcupines have been known to return to feed on the same trees year after year. Hence, high grading would make a habitat less attractive to porcupines (Dodge 1982). However, there is also the possiblity that porcupines may simply move their dens and begin feeding elsewhere. A controlled experiment could be used to test this approach. By the same reasoning, it may be worthwhile to not thin the area near the den, and instead leave an excess of preferred species sacrifice trees to help maintain a higher yield for the stand as a whole. Management for hardwood trees might also provide alternative food in coniferous stands. Again, controlled experiments could be set up to test these methods (Curtis 1941; Sullivan *et al.* 1986).

Pruning trees as a control measure is limited in several ways (Curtis 1941). Firstly, it is a time-consuming process and on a large scale would not be feasible. Secondly, if pruning is not carried out to a considerable extent, the porcupine may still be able to climb the tree. Hence, pruning is not recommended as a large-scale control method.

IMPACT OF DAMAGE ON NSR, STAND TENDING, AND AAC

The information on porcupine population fluctuations indicated a general increase in numbers during the last 25 years as indicated by relatively high levels of feeding damage. This trend is perhaps best reflected by the study of Payette (1987) which describes porcupine response to forest-niche building (i.e. development of second-growth stands on the north coast). The fluctuations reported by Spencer (1964) reflect conditions in mature stands of old growth pinyon pine (*P. edulis*). However, this latter study did give some indication of population fluctuations over a 120-year period. Thus, the two general scenarios of population fluctuations upon which to predict impacts of feeding damage on NSR, stand tending, and AAC are schematically outlined in Figures 2A and B.

Short-term Impact on NSR and Stand Tending

The short-term impact on NSR may be assessed by analyzing porcupine damage and stand data from Khutzeymateen Inlet and Fords Cove in the North Coast Forest District, the Kalum Valley, and from Mitkof Island in Alaska. An underlying assumption in this analysis is that damaged trees may not produce a merchantable stem in the future. Complete girdling will, of course, lead to mortality of the stem above the point of injury producing spike tops with the lower portion of the tree usually still alive. It is unlikely that these latter trees will ever be of commercial value. In addition, Storm and Halvorson (1967) have presented convincing evidence that the sub-lethal (i.e. partial-girdling) removal of bark by porcupines greatly affects the vigour of a tree for up to 10 years, at least in the case of ponderosa pine. It should

also be stressed that any degree of damage to a stem may affect future timber production and/or quality. This could occur by reduced growth via physiological stress from lost vascular tissue and also susceptibility to attack by insects and diseases at the point of injury.

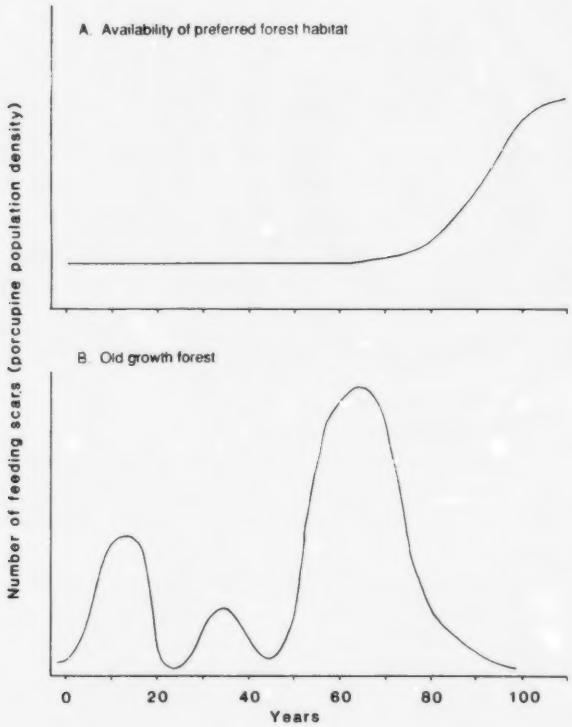

FIGURE 2. General scenarios of porcupine population trends based on (A) long-term increase in abundance in response to availability of preferred forest habitat and (B) fluctuations in porcupine abundance in old growth forest

For second-growth stands in Khutzeymateen Inlet, the incidence of cumulative damage to western hemlock up to 1985 was 52.7% based on an intensive survey (Sullivan *et al.* 1986). In general, porcupines attacked a significantly ($r = 0.89$; $p < 0.01$) greater proportion of large than small diameter trees. Stems smaller than 12.5 cm dbh had little (3.7%) damage. Porcupine attack tended to peak (83.3%) among second-growth hemlock in the 27.5 to 32.4 cm dbh class. Higher levels of attack were recorded for trees ≥ 42.5 cm dbh but these included several veterans of the original forest. The percentage of Sitka spruce trees damaged by porcupines during the 1984-85 winter and prior to this period was 7.8%. Amabilis fir and western redcedar were not attacked. The total incidence of cumulative damage was 63.4% of trees attacked as of spring 1987.

The number of attacks or wounds by porcupines may be considered as a measure of feeding intensity. Porcupines clearly preferred to feed on dominant and co-dominant trees which were usually of larger average diameters than those in the intermediate and suppressed crown classes (Sullivan *et al.* 1986). Significantly more (2.2 to 2.4 times) dominant and co-dominant trees were girdled by porcupines than intermediate and suppressed trees. The total percentage of completely-girdled (direct mortality) stems was 30.9%, and for semi-girdled (50 to 99% of stem circumference) stems was 7.8% (Sullivan *et al.* 1986). Again, porcupines girdled a significantly ($r = 0.87$; $p < 0.01$) greater proportion of large- than small-diameter trees. Those trees with a dbh > 27.4 cm had a total of 55.9% of stems girdled.

Several other studies have reached a similar conclusion that porcupines prefer to feed on large-diameter stems as well as the dominant and co-dominant trees within a given stand (Curtis 1941; Rudolf 1949; Curtis and Wilson 1953; Krefting *et al.* 1962; Van Deusen and Myers 1962). Eglitis and Hennon (1986, 1987) also reported this pattern in Alaska. Evidence for this preference to feed on vigorous stems, based on radial growth analysis, has been reported by Spencer (1964), Storm and Halvorson (1967), and Harder (1979) for various species of conifers in the interior of western North America. A comparable relationships exists for the red squirrel (*Tamiasciurus hudsonicus* Erxleben) and its feeding pattern on juvenile lodgepole pine (Sullivan and Sullivan 1982a and b; Sullivan and Vyse 1987).

A possible conceptual model for describing the impact of this selective attack of *crop* trees by porcupines in second-growth stands is illustrated in Figure 3A. This relationship may be typical of 25- to 35-year-old stands where the porcupine concentrates its feeding on dominant and co-dominant stems, thereby leaving the smaller non-merchantable stems as a major component of the stand. Clearly, this situation will lead to perpetual NSR unless the porcupine population is reduced (by natural or artificial means), or the tree species (e.g. amabilis fir and cedar), which are not preferred at present, eventually comprise the stand.

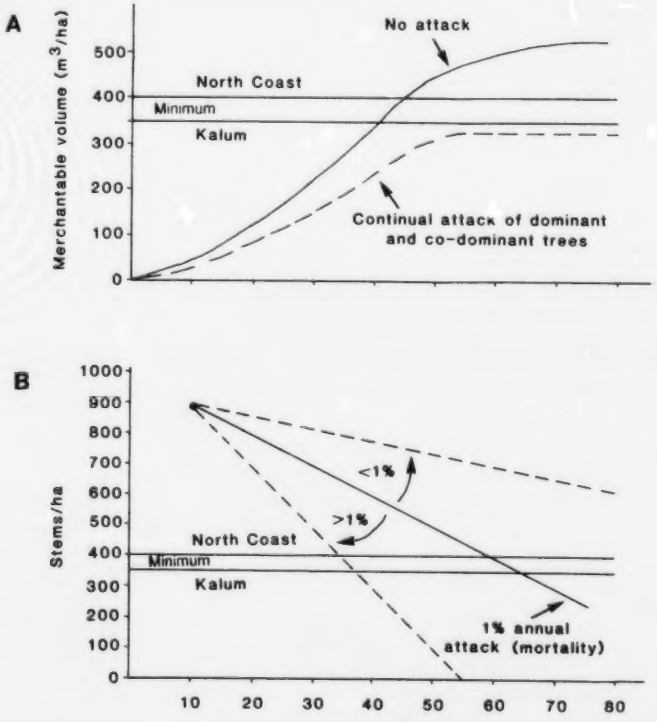

FIGURE 3. Conceptual models of possible impact of feeding damage on NSR in (A) selective attack of dominant and co-dominant trees in unmanaged stands and (B) attack of crop trees in managed stands.

Fords Cove is the other area in the North Coast Forest District that has been surveyed. Incidence of damage was stratified according to: 1. all trees, 2. well-spaced *crop* trees, and 3. estimated attack-size (≥ 10 cm dbh) trees (Table 4)[1]. Again, porcupine preference for potential *crop* trees was significantly higher (> 3 times) than for total trees. Similarly, incidence of attack was twice as high for trees ≥ 10 cm dbh than for all trees. Proportion of girdled tops (spike-tops) also followed this pattern. As suggested in Figure 3A, as small trees become dominant in a stand, they may be at risk to porcupine attack potentially leading to a state of perpetual NSR.

TABLE 4. Incidence (%) of porcupine damage in unmanaged second growth stands at Fords Cove, North Coast Forest District. Sample size (trees/ha) in parentheses. Hw: western hemlock; Ss: Sitka spruce.

	Damage class				Species selection	
Stratum	Pre-1987	1987	Total	Girdled trees	Hw	Ss
Total trees (2916)	8.5	1.4	9.9	4.5	89.3	10.7
Well-spaced trees (920)	27.0	4.5	31.5	14.2	-	-
Attack-size trees (≥ 10 cm dbh) (1458)	17.0	2.8	19.8	9.0	22.2	21.2

The Kalum Forest District has a considerable area of managed stands (stand tending completed in 9086 ha and reforestation of 48 560 ha). The majority of these stands are 12- to 18-years-old and just entering the susceptible-size range for porcupine attack. Surveys conducted in 1986 and 1987 indicated that 0.44% and 1.03%, respectively, of stems overall were newly attacked. The possible impact of a 1% annual loss of crop trees on NSR in managed stands is illustrated in Figure 3B. A free-growing stand of 900 stems/ha at age 10 with an annual loss of 1% would probably still have enough stems (or merchantable volume) at rotation (assuming approximately 1 m^3/tree). However, this conclusion assumes that porcupines do not selectively attack the most vigorous crop trees and other pests (insects, diseases) will not contribute to crop tree mortality. Clearly, these are bold assumptions which must be carefully reviewed. Damage may decline in accordance with porcupine population fluctuations or control. Alternatively, the annual rate of attack may increase (> 1%) thereby resulting in an NSR condition.

The porcupine population increase outlined in Figure 2A, which suggests a continual increase in abundance in accordance with availability of habitat, may be occurring in the Kalum Valley. The annual rate of attack has increased from 0.6% (1986) to 1.8% (1987) for western hemlock in managed stands, and this species is the major component of most stands (Figure 4A). Damage to Sitka spruce has remained constant at 0.84% (1986) and 0.75% (1987) (Figure 4A). Cumulative attack levels of 6.5% for hemlock and 3.0% for spruce have been recorded since the stands were thinned.

Porcupine attack of precommercially thinned (1985) stands (12-20 years of age) in Alaska is particularly severe with annual damage increasing from 10.9% (1986) to 17.2% (1987) for Sitka spruce, which comprises 62% of the stands sampled (Figure 4B) (Eglitis and Hennon 1986, 1987). Attack of western hemlock was 7.1% (1986) and 6.7% (1987). Cumulative damage was 25% of hemlock and 51%

[1] Data from W. Jackson, Protection Section, North Coast Forest District, Prince Rupert, B.C.

of spruce crop trees attacked by porcupines. This rather sobering situation is further intensified by the annual rate of complete girdling of crop trees at 3.9%. Although serious damage in Alaska is restricted to Mitkof Island, this example may represent the future damage situation for managed stands in the Kalum Valley.

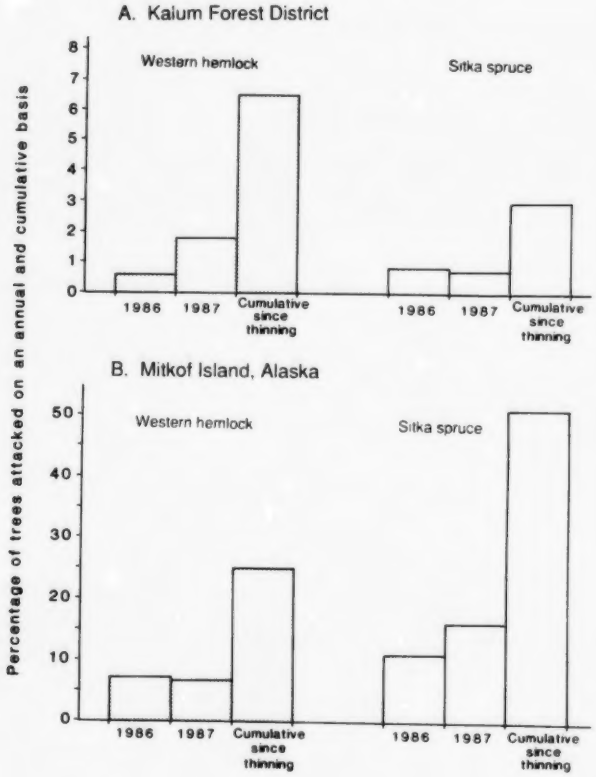

FIGURE 4. Percentage of trees attacked on an annual and cumulative basis in managed stands in (A) the Kalum Forest District and (B) Mitkof Island, Alaska.

Clearly, stand-tending practices such as juvenile and sanitation spacing leave crop trees at risk to porcupine attack. Both western hemlock and Sitka spruce are attacked and this may depend on their relative densities in a given managed stand. Lodgepole pine is also attacked in the Kalum Valley. Since the vigorous growth of trees in thinned stands apparently predisposes them to preferential attack, fertilization of such stands would likely make the damage situation even worse. In terms of other small mammal species, fertilization of lodgepole pine on an experimental basis in the central interior significantly increased attacks of crop trees by both snowshoe hares and red squirrels (Sullivan and Sullivan 1982b; Brockley and Sullivan 1987).

Long-term Impact on AAC

The long-term impact of damage on AAC may be viewed conceptually on an incremental or catastrophic basis. The increasing attack rate of trees in managed stands in the Kalum Valley suggests an incremental effect on merchantable volume/area, thereby lengthening the rotation (Figure 5A). This increase in damage may or may not result in the catastrophic effect recorded in stands on Mitkof Island. Clearly, a consistent annual mortality (complete girdling) rate of 3.9% with a cumulative 50% of the dominant crop trees (e.g. spruce) attacked, by age 20, is a catastrophic situation, at least on a local basis

(Figure 5B). A natural decline in the porcupine population, or reduction of damage via introduction of fishers or an effective bounty system, for example, may result in only periodic outbreaks of damage. The incremental attack in the Kalum Valley could become catastrophic in the near future if present trends continue. In both cases, the rotation is lengthened to reach minimum merchantable volume. These are two *worst-case* scenarios which assume porcupine populations will continue increasing in abundance and expanding in range in accordance with availability of preferred habitat.

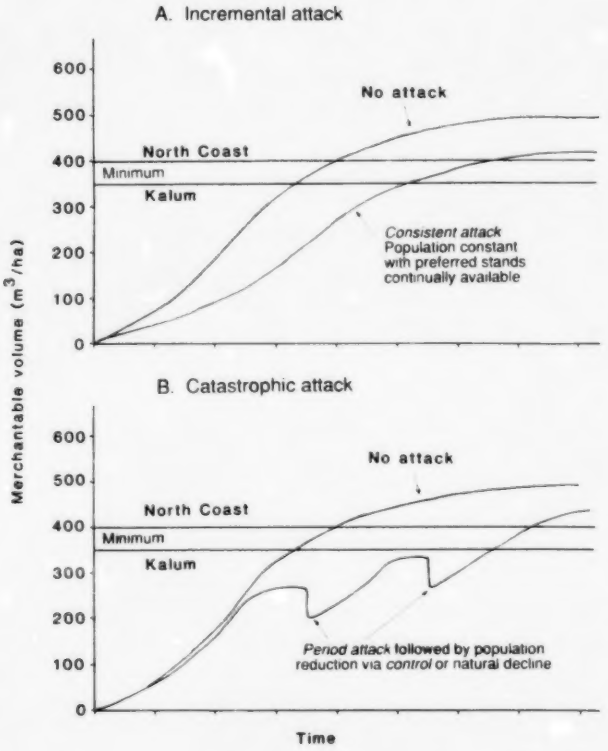

FIGURE 5. Conceptual models of the possible impact of feeding damage on AAC in terms of (A) incremental attack and (B) catastrophic attack.

FORECAST MODEL

A first approximation of a forecast model to predict *when* and *where* outbreaks of porcupine damage will occur is illustrated in Figure 6. The CWHf and CWHi and CWHj subzones in the Kalum and North Coast Forest Districts, respectively, currently have damage in stands ranging from 15 to 35 years old. These stands provide winter-feeding areas and nearby early successional (post-harvest) stages are where porcupines presumably concentrate their summer feeding. Combined with a moderate climatic trend (e.g. mild winters) and a reduction in the predator population, these favourable habitat conditions lead to a porcupine population increase. Such increases appear to occur over long periods (decades) and may persist indefinitely unless interrupted by catastrophic weather conditions (e.g. severe winter) or a management program. Therefore, it is difficult to evaluate the existence or frequency of cyclic behaviour in porcupine populations on the north coast. In addition, population densities are currently unknown. This

increase in porcupine populations leads to an outbreak of feeding damage in susceptible stands. Initial surveys of damage suggest that managed stands may increase the intensity of attack, thereby leading to a potential NSR status for many stands.

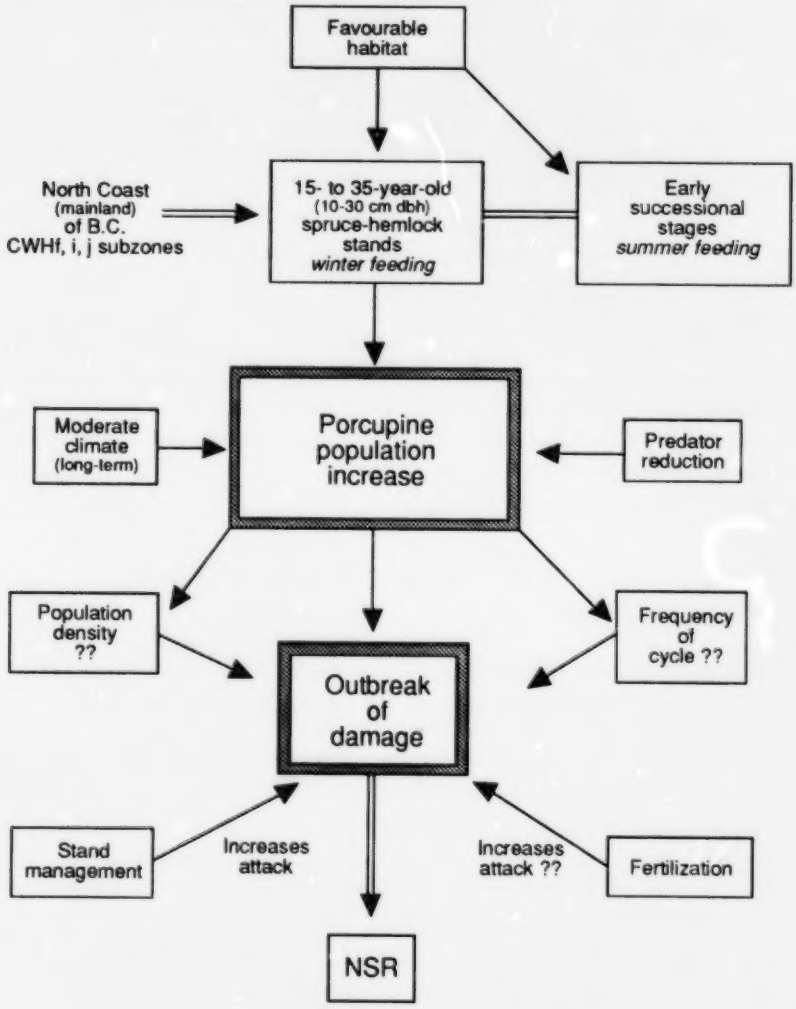

FIGURE 6. First approximation of a forecast model to predict when and where outbreaks of porcupine damage will occur in the Kalum and North Coast Forest Districts.

PLAN OF ACTION

Detection of Damage

1. Surveys of damage should be conducted on an annual basis using permanent plots or transects.
   a. The 48 km of survey line in managed stands in the Kalum Valley must be continued to provide annual data on incidence of attack. This is particularly important since these stands are entering the susceptible stage for intensive porcupine attack.
   b. Additional second-growth stands in the North Coast Forest District should be surveyed to determine the damage incidence on a district-wide basis.
2. Transect surveys in managed stands should continue using the same methodology of 2 m wide strips. Surveys in natural stands should use permanent plots located at 50- to 100-m intervals along transects. These transects should be located to provide maximum coverage of all terrain types within a given survey area. Variable plot cruise sampling may be used to identify sample trees (≥ 7.5 cm dbh) in each plot. Species, dbh, crown class, *old* and *current* damage wounds, and spike-tops should be tallied for each tree.
3. Surveys should be concentrated in susceptible areas as outlined in the forecast model.
4. Surveys may be used to assess effectiveness of population and damage-reduction techniques.

Recommendations to Alleviate Damage

1. Bounty system to reduce porcupine populations on a short-term basis.
   a. Must be done with persistence and commitment by participants in the field and regulators within the Ministry of Forests.
   b. Strongly suggest that bounty be raised to $20-$50/animal to provide sufficient incentive. If 10 ha of spacing costs approximately $10 000, then for this sum of money, a bounty of $20-$50 would pay for 200-500 porcupines. Use of live-traps could also be continued as part of the bounty system.
   c. Best suited for Kalum Valley and similar areas with good access.
   d. Some degree of regulation (e.g. registered trappers/hunters only or perhaps organized hunts) is essential.
   e. A control (check) area must be set aside to allow assessment of efficacy.
2. Introduction of fisher to reduce porcupine populations on a long-term basis.
   a. Must procure a consistent supply of fishers from somewhere in North America.
   b. Best suited for inaccessible sites such as Khutzeymateen Inlet and similar areas with poor access.
   c. Fur trapping in area of *introduction* must be curtailed with appropriate compensation, otherwise a resident population of fisher cannot be established.

d. A control (check) area should be established, if possible, to help assess efficacy.

3. Where possible, in spacing/planting programs, leave/plant a greater number of trees/ha (e.g. a post-spacing density of 1200 to 1600 stems/ha rather than 900, a post-planting density of 2000 trees/ha rather than 1200-1400).

   a. Flexibility - accomodate tree mortality from future attack by porcupines and other pest agents such as insects and disease.

   b. Potential for second pass - precommercial/ commercial thinning.

   c. May also be considered as a method of leaving sacrifice trees for porcupines.

4. Select for less-preferred species (in terms of porcupine attack) such as amabilis fir and western redcedar in spacing/planting programs - subject to experimental results concluding that porcupines will not attack these species even when they comprise a major part of a managed stand.

5. Continuation of proposed communications plan to educate members of public in North Coast and Kalum Forest Districts on the porcupine damage problem. This plan is based on a pest leaflet, mall display, video, and specific instruction within the school system. The plan is designed to make people aware of the problem and the alternative methods available to deal with it.

INFORMATION AND RESEARCH NEEDS

1. Assessment of the impact of partial girdling on tree growth and yield in the Khutzeymateen Inlet stands should be continued at 5-year intervals. Additional growth and yield plots should be established in porcupine-damaged stands at other sites in the North Coast Forest District. Growth and yield plots (or use of already existing plots) should also be set up in managed stands in the Kalum Valley.

2. Decay samples should be analyzed for wood-rot fungi (in addition to those from Khutzeymateen Inlet) in association with surveys of other second-growth stands in the North Coast Forest District.

3. Commence a population study of porcupines in the Kalum Valley to determine densities in managed and natural stands as well as seasonal migrations. This study would help determine how many porcupines are attacking trees, and could be superimposed on areas of intensive hunting (treatment) and a check (control) to help assess efficacy of population reduction program. If the study was continued at a basic level over several years in the check area, the population trend would become apparent. Basic population monitoring would involve mark and recapture sampling on a grid system during a certain number (minimum of two) of sampling periods each year. Monitoring of movements would require radio telemetry of collared (transmitter) animals.

4. Assessment of the effects of stand-density manipulation and tree-species selection on porcupine damage in managed stands.

5. Assessment of porcupine preference for hardwood species compared with conifers and examine the potential use of hardwoods as alternative food in susceptible stands.

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